Chapter 3. Water Quality

Introduction

The City of San Diego collects and analyzes seawater samples from along the shoreline and in offshore ocean waters of the region surrounding the Point Loma Ocean Outfall (PLOO) to characterize water quality conditions in the region and to identify possible impacts of wastewater discharge on the marine environment. Densities of fecal indicator bacteria (FIB), including total coliforms, fecal coliforms, and enterococcus, are measured and evaluated along with data on local oceanographic conditions (see Chapter 2) to provide information about the movement and dispersion of wastewater discharged into the Pacific Ocean through the outfall. Evaluation of these data may also help to identify other point or non-point sources of bacterial contamination. In addition, the City's water quality monitoring program is designed to assess compliance with water contact standards as established in the California Ocean Plan (Ocean Plan), which defines bacterial water quality objectives and standards with the intent of protecting the beneficial uses of State ocean waters (SWRCB 2001, 2005).

Because there are multiple natural and anthropogenic point and non-point sources that can impact water quality, distinguishing a wastewater plume from other sources of bacterial contamination in ocean waters is often challenging. In the PLOO region, multiple sources of potential bacterial contamination exist in addition to the outfall itself, including tidal exchange from San Diego Bay, outflows from the Tijuana River, the San Diego River and coastal lagoons in northern San Diego County, storm water discharges, and runoff from local watersheds (Noble et al. 2003, Griffith et al. 2009, Svejkovsky 2011). Likewise, it has been shown that kelp and seagrass beach wracks, storm drains impacted by tidal flushing, and beach sediments can act as reservoirs, cultivating bacteria until high tide returns and/or other disturbances release them into nearshore waters (Gruber et al. 2005, Martin and Gruber 2005). Finally, the presence of birds and their droppings have been related to bacterial exceedances that may impact nearshore water quality (Grant et al. 2001, Griffith et al. 2009).

This chapter presents analyses and interpretation of FIB densities and ammonia data collected during 2010 at monitoring sites surrounding the PLOO. The primary goals are to: (1) evaluate overall water quality conditions in the region, (2) differentiate among various sources of bacterial contamination in the survey area, including the PLOO wastewater plume, (3) evaluate potential movement and dispersal of wastewater discharged via the PLOO, and (4) assess compliance with water contact standards as defined in the Ocean Plan.

Materials and Methods

Field Sampling

Shore stations

Seawater samples for bacteriological analyses were collected at eight shore stations (i.e., stations D4, D5, and D7–D12; Figure 3.1) to monitor FIB concentrations in waters adjacent to public beaches and to evaluate compliance with Ocean Plan water contact standards (see Box 3.1). Seawater samples were collected from the surf zone in sterile 250-mL bottles at each station five times during the month. In addition, visual observations of water color, surf height, human or animal activity, and weather conditions were recorded at the time of collection. The samples were then transported on blue ice to the City of San Diego's Marine Microbiology Laboratory (CSDMML) and analyzed to determine concentrations of total coliform, fecal coliform, and enterococcus bacteria.

Kelp bed and offshore stations

Eight stations located in nearshore waters within the Point Loma kelp forest were sampled weekly to assess water quality conditions and Ocean Plan

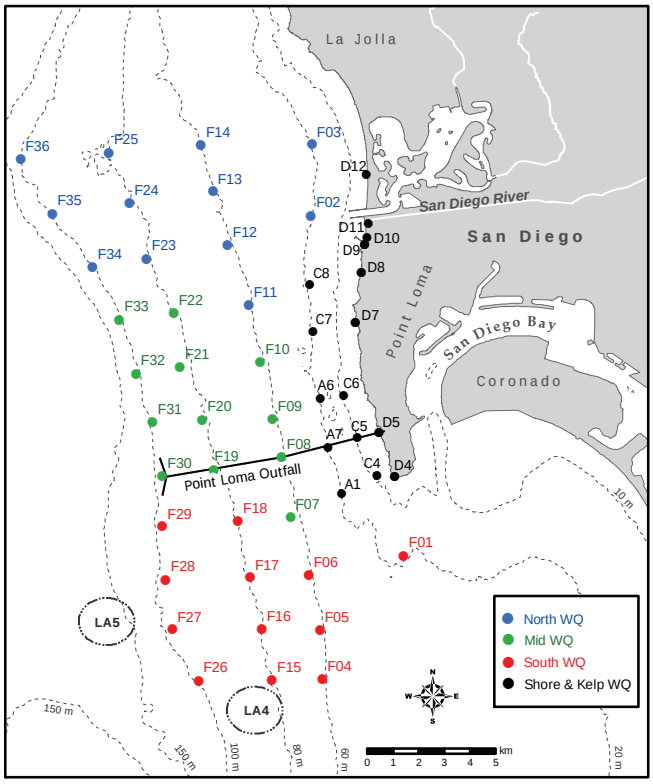

Figure 3.1
Water quality (WQ) monitoring stations for the Point Loma Ocean Outfall Monitoring Program.

compliance in areas used for recreational activities such as SCUBA diving, surfing, fishing, and kayaking. These included stations C4, C5 and C6 located near the inner edge of the kelp bed along the 9-m depth contour, and stations A1, A6, A7, C7 and C8 located near the outer edge of the kelp bed along the 18-m depth contour (Figure 3.1). As at the shore stations, weekly monitoring at each of the kelp bed sites primarily consisted of collecting seawater samples to determine concentrations of total coliform, fecal coliform, and enterococcus bacteria. Starting in August, samples for ammonia analysis were collected at these same sites on a quarterly basis to correspond with sampling at the offshore stations located within State waters (see below). During the last quarter of 2010, however, the quarterly ammonia samples for these eight sites were collected during December instead due to a sampling oversight the previous month.

An additional 36 stations located further offshore were sampled in order to monitor FIB levels in these deeper waters and to estimate dispersion of the wastewater plume. These offshore stations are arranged in a grid surrounding the discharge site along or adjacent to the 18, 60, 80, and 98-m depth contours (Figure 3.1). In contrast to shore and kelp bed stations, monitoring at all offshore sites was conducted on a quarterly basis, typically during the months of February, May, August and November, with each survey usually occurring over a 3-day period. However, sampling during the first quarter of 2010 was delayed until March to accommodate a Bight'08 Water Quality Survey that was postponed until this year (see Table 2.1 for the specific dates each survey was conducted). For the first half of 2010 (i.e., March and May), samples collected from these sites were analyzed for densities of total coliform, fecal coliform, and enterococcus; however, analyses of these samples were limited to enterococcus only following the transition to bacterial compliance standards specified in the 2005 Ocean Plan which became effective August 1, 2010 (see Data Treatment section below). At the same time, monitoring for ammonia began at the same discrete depths where bacterial samples were collected at the 15 offshore stations located within State jurisdictional waters (i.e., within 3 nautical miles of shore).

Seawater samples for the kelp and offshore stations were collected at 3–5 discrete depths per site dependent upon station depth (see Table 3.1). These samples were collected using either an array of Van Dorn bottles or a rosette sample fitted with Niskin bottles. Aliquots for ammonia and bacteriological analyses were drawn from these bottles into sterile sample bottles for processing at the City's Toxicology Laboratory and CSDMML, respectively. Visual observations of weather and sea conditions, and human or animal activity were also recorded at the time of sampling.

Laboratory Analyses

All bacterial analyses were performed within 8 hours of sample collection and conformed to standard membrane filtration techniques (APHA 1998). The CSDMML follows guidelines issued by the United States Environmental Protection Agency (USEPA)

Box 3.1

Bacteriological compliance standards for water contact areas, 2001 California Ocean Plan (SWRCB 2001). CFU = colony forming units.

(a) *30-day Total Coliform Standard* — no more than 20% of the samples at a given station in any 30-day period may exceed a concentration of 1000 CFU per 100 mL.

(b) *10,000 Total Coliform Standard* — no single sample, when verified by a repeat sample collected within 48 hrs, may exceed a concentration of 10,000 CFU per 100 mL.

(c) *60-day Fecal Coliform Standard* — no more than 10% of the samples at a given station in any 60-day period may exceed a concentration of 400 CFU per 100 mL.

(d) *30-day Fecal Geometric Mean Standard* — the geometric mean of the fecal coliform concentration at any given station in any 30-day period may not exceed 200 CFU per 100 mL, based on no fewer than five samples.

Bacteriological compliance standards for water contact areas, 2005 California Ocean Plan (SWRCB 2005). CFU = colony forming units.

(a) *30-day Geometric Mean* — The following standards are based on the geometric mean of the five most recent samples from each site:
   1) Total coliform density shall not exceed 1000 CFU/100 mL.
   2) Fecal coliform density shall not exceed 200 CFU/100 mL.
   3) Enterococcus density shall not exceed 35 CFU/100 mL.

(b) *Single Sample Maximum*:
   1) Total coliform density shall not exceed 10,000 CFU/100 mL.
   2) Fecal coliform density shall not exceed 400 CFU/100 mL.
   3) Enterococcus density shall not exceed 104 CFU/100 mL.
   4) Total coliform density shall not exceed 1000 CFU/100 mL when the fecal coliform:total coliform ratio exceeds 0.1.

Water Quality Office, Water Hygiene Division, and the California State Department of Health Services (CDHS) Environmental Laboratory Accreditation Program (ELAP) with respect to sampling and analytical procedures (Bordner et al. 1978, APHA 1998).

Procedures for counting colonies of indicator bacteria, calculation and interpretation of results, data verification and reporting all follow guidelines established by the USEPA (Bordner et al. 1978) and APHA (1998). According to these guidelines, plates with FIB counts above or below the ideal counting range were given greater than (>), less than (<), or estimated (e) qualifiers. However, these qualifiers were dropped and the counts treated as discrete values when calculating means and in determining compliance with Ocean Plan standards.

Quality assurance (QA) tests were performed routinely on seawater samples to ensure that sampling variability did not exceed acceptable limits. Duplicate and split bacteriological samples were processed according to method requirements to measure intra-sample and inter-analyst variability, respectively. Results of these procedures were reported in City of San Diego (2011a).

Additional seawater samples were analyzed for ammonia (as nitrogen) by the Salicylate Method using a Hach DR850 colorimeter. Quality assurance tests for these analyses were performed using blanks.

Data Treatment

FIB densities were summarized as monthly averages for each shore station and by depth contour for the

Table 3.1
Depths at which seawater samples are collected for bacteriological analysis at the PLOO kelp bed and offshore stations.

Station Contour	Sample Depth (m)								
	1	3	9	12	18	25	60	80	98
Kelp Bed									
9-m	x	x	x						
18-m	x			x	x				
Offshore									
18-m	x			x	x				
60-m	x					x	x		
80-m	x					x	x	x	
98-m	x					x	x	x	x

kelp stations. To assess temporal and spatial trends, bacteriological data were summarized as counts of samples in which FIB concentrations exceeded benchmark levels. For this report, water contact limits defined in the 2005 Ocean Plan for densities of total coliforms, fecal coliforms, and enterococcus in individual samples (i.e., single sample maxima; see Box 3.1 and SWRCB 2005) were used as reference points to distinguish elevated FIB values (or benchmarks). Concentrations of each FIB are identified by sample in Appendices B.1, B.2, and B.3. In addition, the 2005 Ocean Plan single sample maximum standard that states total coliform densities shall not exceed 1000 CFU/100 mL when the fecal coliform:total coliform (F:T) ratio exceeds 0.1 was considered as the criterion for contaminated waters. This condition is referred to as the fecal:total ratio (FTR) criterion herein. Since enterococcus was the only type of bacteria measured in samples from the 36 offshore sites between August and December (see above), analyses were limited to this parameter for the entire year. Finally, Pearson's Chi-Square analyses (χ^2) were conducted to determine if the frequency of samples with elevated FIBs differed between wet versus dry seasons.

Compliance with Ocean Plan water-contact standards was summarized as the number of days that each of the shore stations and all of the kelp bed stations exceeded various Ocean Plan standards during each month. Due to regulatory changes that became effective August 1, 2010, bacterial compliance was assessed using the water contact standards specified in the 2001 Ocean Plan (Box 3.1 and SWRCB 2001) between January 1 and July 31, 2010, whereas data collected after August 1, 2010 were assessed using the standards specified in the 2005 Ocean Plan (Box 3.1 and SWRCB 2005).

RESULTS

Distribution of FIBs

Shore stations

As in previous years, concentrations of indicator bacteria were generally low along the Point Loma shoreline in 2010. Monthly FIB densities at the individual shore stations averaged from 2 to 3254 CFU/100 mL for total coliforms, 2 to 93 CFU/100 mL for fecal coliforms, and 2 to 149 CFU/100 mL for enterococcus (Table 3.2). As expected, the highest values for each parameter occurred between January–April and October–December when rainfall totaled 16.2 inches (vs. 0.08 inches in the dry season). In fact, each of the 12 shore station samples with elevated FIBs and each of the two samples that exceeded the FTR criterion were collected during these wet season months (Table 3.3, Appendix B.1) when rain events cause turbidity plumes that can impact the area. For example, a Rapid Eye satellite image taken December 24, 2010 showed turbidity plumes encompassing several of the shore stations, seven of which had elevated enterococcus concentrations on the previous day (Figure 3.2). While the image in this figure was not taken on the same day the bacterial samples were collected, the turbidity plume that is evident likely started earlier in the week due to a large storm that began December 21, 2010. This general relationship between rainfall and elevated bacteria levels has been somewhat evident over the past several years (Figure 3.3); these data indicate that there is 5% greater chance of collecting a sample with elevated FIBs during the wet season than during the dry season [$\chi^2(1,\ N=1963)=19.9,\ p<0.001$].

Table 3.2

Summary of rainfall and bacteria levels at PLOO shore stations during 2010. Total coliform, fecal coliform, and enterococcus densities are expressed as mean CFU/100 mL per month and for the entire year. Rain data are from Lindbergh Field, San Diego, CA. Stations are listed north to south from top to bottom; *n* = total number of samples.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010 Total Rain (in)		3.38	2.30	0.68	1.78	0.01	0.02	0.02	0.00	0.03	2.18	0.88	5.00
D12	*Total*	157	129	9	4	16	28	26	16	13	672	131	264
	Fecal	8	4	2	2	2	3	2	5	2	29	7	23
	Entero	20	3	2	2	2	4	4	2	3	43	7	123
D11	*Total*	200	3254	1260	1864	44	20	28	16	34	145	272	652
	Fecal	13	70	33	54	15	4	6	7	4	8	8	30
	Entero	30	122	14	6	16	22	16	3	6	12	14	83
D10	*Total*	505	101	172	116	20	32	30	17	80	40	300	452
	Fecal	6	4	12	8	3	5	3	2	6	5	20	14
	Entero	25	4	5	3	2	2	2	2	18	8	31	38
D9	*Total*	44	538	156	25	32	56	66	17	13	28	96	129
	Fecal	2	12	5	2	2	2	3	2	2	4	10	8
	Entero	4	15	4	2	7	2	2	2	2	16	10	28
D8	*Total*	ns	ns	ns	ns	252	60	20	49	96	125	328	352
	Fecal	ns	ns	ns	ns	2	2	2	4	8	93	43	51
	Entero	ns	ns	ns	ns	2	2	4	2	7	40	15	77
D7	*Total*	80	53	11	2	14	52	58	124	95	120	28	216
	Fecal	3	2	2	2	2	2	2	7	9	71	11	28
	Entero	13	2	2	2	2	3	3	5	2	149	4	76
D5	*Total*	66	90	8	9	16	16	20	13	56	256	232	456
	Fecal	5	2	2	2	2	2	2	2	2	27	6	54
	Entero	2	2	2	2	2	2	2	2	2	2	22	107
D4	*Total*	41	9	6	4	9	46	31	16	44	96	49	1125
	Fecal	4	2	2	2	2	2	2	3	3	3	8	63
	Entero	2	2	2	2	2	2	2	2	5	2	3	58
	n	33	35	35	35	40	40	48	40	40	40	40	40
Annual Means	*Total*	156	596	232	289	50	39	35	34	54	185	180	456
	Fecal	6	14	8	10	4	3	3	4	5	30	14	34
	Entero	14	21	4	3	4	5	4	3	6	34	13	74

ns = not sampled (no samples were collected at station D8 from January 1 to April 26 due to shoreline inaccessibility)

Kelp bed stations

Concentrations of indicator bacteria were also generally low at the eight kelp bed stations in 2010. For example, monthly FIB densities at these stations averaged about 2 to 232 CFU/100 mL for total coliforms, 2 to 5 CFU/100 mL for fecal coliforms, and 2 to 45 CFU/100 mL for enterococcus (Table 3.4). Of the 1431 seawater samples collected from these sites during the year, only six samples (0.4%) had elevated FIBs and none of the samples

Table 3.3

The number of samples with elevated bacteria densities collected at PLOO shore stations during 2010. Elevated FIB = total number of samples with elevated FIBs; contaminated = total number of samples that meet the fecal:total coliform ratio criterion indicative of contaminated waters; wet season = January–April and October–December; dry season = May–September; *n* = total number of samples. Rain data are from Lindbergh Field, San Diego, CA. Stations are listed north to south from top to bottom.

Station		Season		
		Wet	Dry	% Wet
D12	Elevated FIB	2	0	100
	Contaminated	0	0	—
D11	Elevated FIB	2	0	100
	Contaminated	0	0	—
D10	Elevated FIB	2	0	100
	Contaminated	0	0	—
D9	Elevated FIB	0	0	—
	Contaminated	0	0	—
D8	Elevated FIB	2	0	100
	Contaminated	1	0	100
D7	Elevated FIB	2	0	100
	Contaminated	0	0	100
D5	Elevated FIB	1	0	100
	Contaminated	1	0	100
D4	Elevated FIB	1	0	100
	Contaminated	0	0	—
	Rain (in)	16.20	0.08	
Total Counts	Elevated FIB	12	0	100
	Contaminated	2	0	100
	n	258	208	

Figure 3.2

Rapid Eye satellite image showing the PLOO monitoring region on December 24, 2010 (Ocean Imaging 2011) combined with enterococcus concentrations at shore stations sampled on December 22, 2010. Turbid waters from the San Diego River, San Diego Bay, and from other sources to the south can be seen overlapping PLOO shore stations.

exceeded the FTR criterion (Appendix B.2). Half of the samples with elevated FIBs were collected in the wet season and may have been associated with rainfall events (Table 3.5). The source of contamination in the three samples with elevated FIBs collected in the dry season remains unclear.

Offshore stations

Concentrations of enterococcus bacteria reached 920 CFU/100 mL in samples collected from the 36 offshore stations during 2010 (Appendix B.3). However, only 15 of 564 samples (~2.7%) had elevated enterococcus levels, all of which were collected at depths ≥60 m from just six stations located along the 80 and 98-m depth contours (Figure 3.4). These results suggest that the wastewater plume remained restricted to relatively deep, offshore waters throughout the year and are consistent with remote sensing observations that provided no evidence of the plume reaching surface waters in 2010 (Svejkovsky 2011).

California Ocean Plan Compliance

Overall compliance with Ocean Plan standards in 2010 was 99.7%. Compliance was lowest in January–March and October–December when rainfall was greatest. During the first seven months of the year (i.e., January–July), all eight kelp bed and six of the eight shore stations were in complete compliance with all four of the 2001 Ocean Plan standards (Appendix B.4). Only shore stations D8 and D11 fell below 100% compliance, with all but one of the exceedances occurring during the wet season. For example, the 30-day total coliform standard was exceeded at station D8 in January

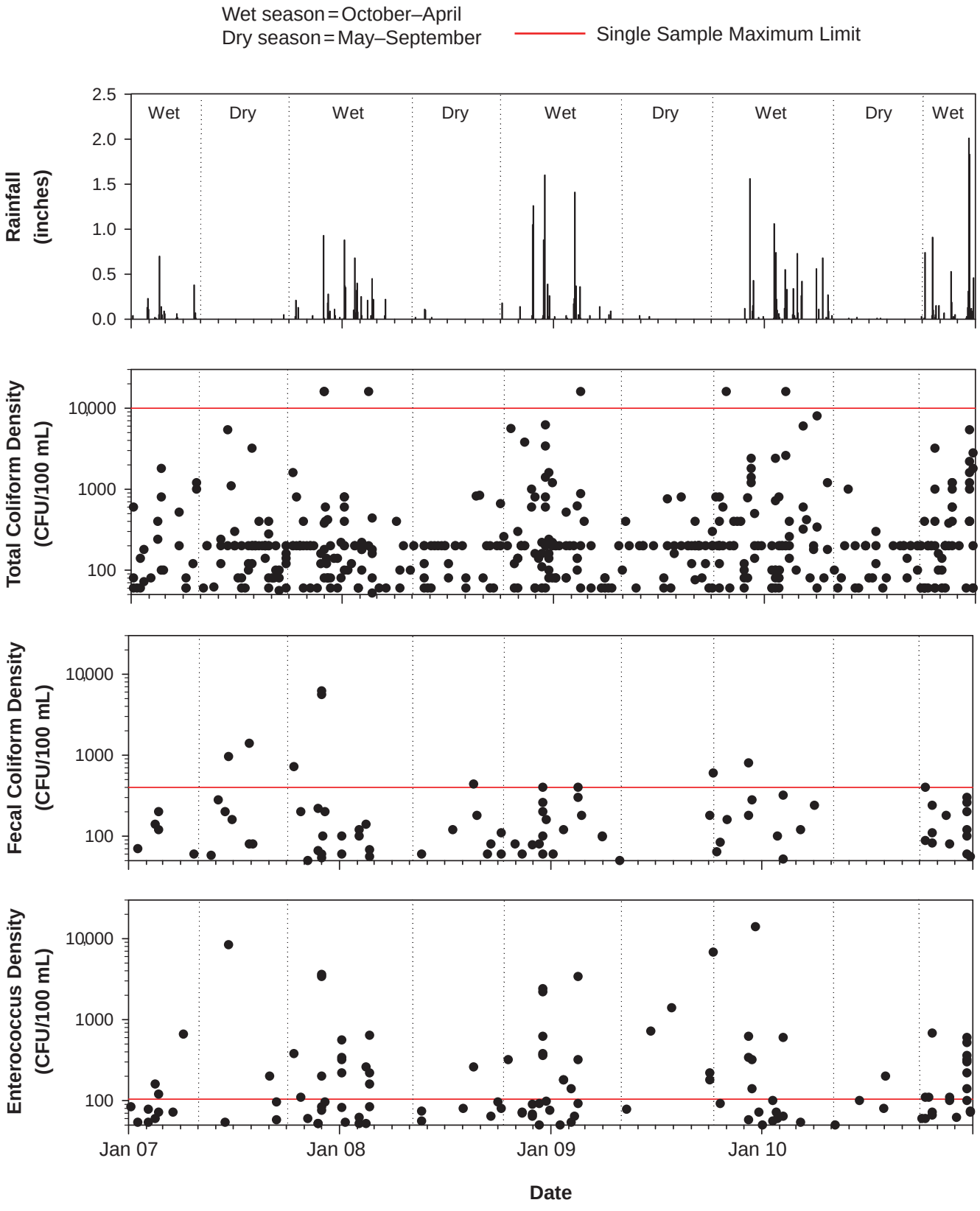

Figure 3.3

Comparison of bacteriological data from PLOO shore stations to rainfall between January 1, 2007 and December 31, 2010. Densities of bacteria have been limited to ≥50 CFU/100mL for clearer data presentation.

Table 3.4

Summary of FIB densities (CFU/100 mL) at PLOO kelp bed stations in 2010. Total coliform, fecal coliform, and enterococcus data are expressed as means for all stations along each depth contour by month; *n*=total number of samples per month.

Assay	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
9-m Depth Contour												
Total	4	2	3	3	3	6	4	4	3	8	10	11
Fecal	2	2	2	2	2	2	2	2	2	2	2	2
Entero	3	2	8	2	2	2	2	2	2	2	2	2
n	45	36	45	45	45	45	45	45	45	45	45	45
18-m Depth Contour												
Total	31	10	34	10	25	4	16	6	5	16	232	20
Fecal	3	2	4	3	2	2	3	2	2	2	5	2
Entero	8	2	45	3	15	2	2	5	2	2	2	3
n	75	75	75	75	75	75	75	75	75	75	75	75

and at station D11 during February, March, April and May, which resulted in 97% and 77% overall compliance with this standard, respectively. During the last five months of the year (i.e., August–December), all of the kelp bed and all but one of the shore stations were in complete compliance with the 2005 Ocean Plan 30-day geometric mean standards for total coliforms, fecal coliforms, and enterococcus (Appendix B.5). The only exception occurred at shore station D11 in December. Additionally, the four single sample maximum (SSM) standards in the 2005 Ocean Plan were exceeded just once at the kelp bed stations (i.e., the total coliform SSM exceedance at station A7 in November), while all of the offshore stations within State waters were in complete compliance with the SSM for enterococcus. While the SSMs for total and fecal coliform bacteria were never exceeded at the shore stations during the latter part of 2010, and the FTR was only exceeded twice in December (once each at D5 and D8), several of the shore stations exceeded the SSM for enterococcus during October, November and December.

Ammonia was detected in 48% of the 144 samples collected from PLOO stations in 2010 at concentrations up to 0.16 mg/L. These ammonia levels were substantially lower than the water quality objectives defined in the 2005 Ocean Plan (i.e., instant maximum of 6.0 mg/L, daily maximum of 2.4 mg/L; SWRCB 2005). Overall, ammonia was found in samples from 22 of 23 stations surveyed during August (Figure 3.5). The highest concentration was detected in surface water at station F02 located offshore of the mouth of the San Diego River and Mission Bay. Other relatively high ammonia concentrations >0.10 mg/L were also detected throughout the water column at kelp bed stations C4, A1, A7 and A6 and at offshore stations F8, F9 and F19. Ammonia was detected less frequently during the fourth quarter, occurring at only six stations and at concentrations below 0.07 mg/L. None of the samples with detectable concentrations of ammonia contained elevated concentrations of enterococcus bacteria (Figure 3.4; City of San Diego 2011b).

Discussion

Water quality conditions in the Point Loma outfall region were excellent during 2010, as indicated by an overall 99.7% compliance rate with Ocean Plan water-contact standards. In addition, there was no evidence during the year that wastewater discharged to the ocean via the PLOO reached the shoreline or nearshore recreational waters. Although elevated FIB densities were detected occasionally along the shoreline and at the kelp bed stations, concentrations of these bacteria tended to be relatively low overall. In fact, only two of the seawater samples collected during the year met

Table 3.5

The number of samples with elevated bacteria collected at PLOO kelp bed stations during 2010. Elevated FIB = total number of samples with elevated FIBs; contaminated = total number of samples that meet the fecal:total coliform ratio criterion indicative of contaminated waters; wet season = January–April and October–December; dry season = May–September; *n* = total number of samples. Rain data are from Lindbergh Field, San Diego, CA.

		Season		
Station		**Wet**	**Dry**	**% Wet**
9-m Depth Contour				
C6	Elevated FIB	0	0	—
	Contaminated	0	0	—
C5	Elevated FIB	0	0	—
	Contaminated	0	0	—
C4	Elevated FIB	1	0	100
	Contaminated	0	0	—
18-m Depth Contour				
A6	Elevated FIB	0	1	0
	Contaminated	0	0	—
A7	Elevated FIB	1	2	33
	Contaminated	0	0	—
A1	Elevated FIB	1	0	100
	Contaminated	0	0	100
C8	Elevated FIB	0	0	—
	Contaminated	0	0	—
C7	Elevated FIB	0	0	—
	Contaminated	0	0	—
	Rain (in)	16.20	0.08	
Total	Elevated FIB	3	3	50
Counts	Contaminated	0	0	100
	n	831	600	

the FTR criterion for contaminated waters, and no samples had elevated levels of fecal coliform bacteria. Over the years, elevated FIBs detected at shore and kelp bed stations have tended to be associated with rainfall events, heavy recreational use, or the presence of seabirds or decaying kelp and surfgrass (e.g., City of San Diego 2009). During 2010, all of the elevated bacterial densities along the shore occurred between the months January–April and October–December, during which time there was a total of 16.2 inches of rain.

Previous analyses of water quality data for the region have indicated that the PLOO wastefield has typically remained well offshore and submerged in deep waters since the extension of the outfall was completed in late 1993 (City of San Diego 2007, 2008, 2009, 2010a). This pattern remained true for 2010 with evidence of the wastewater plume restricted to depths of 60 m or below in offshore waters. Moreover, no visual evidence of the plume surfacing was detected in aerial or satellite imagery during 2010 (Svejkovsky 2011). The deepwater (98 m) location of the discharge site may be the dominant factor that inhibits the plume from reaching surface waters. For example, wastewater released into these deep, cold and dense waters does not appear to mix with the top 25 m of the water column. Finally, it appears that not only is the plume from the PLOO being trapped below the thermocline, but now that effluent is undergoing chlorination prior to discharge, densities of indicator bacteria in local receiving waters have dropped substantially (see City of San Diego 2010a).

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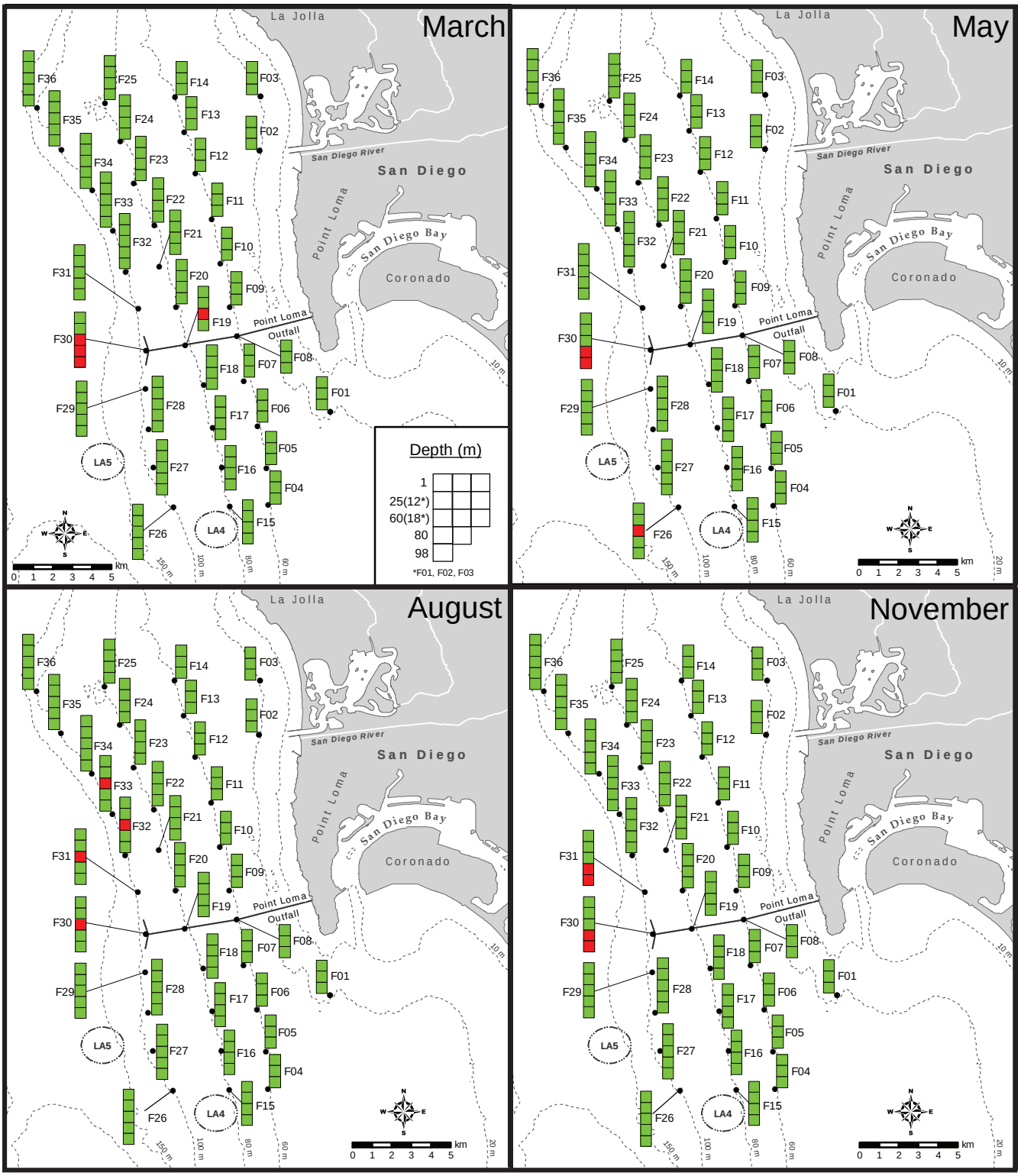

Figure 3.4

Distribution of seawater samples collected during the PLOO quarterly surveys in 2010 that contained elevated densities of enterococcus (i.e., >104 CFU/100 mL; red squares). See text and Table 2.1 for sampling details.

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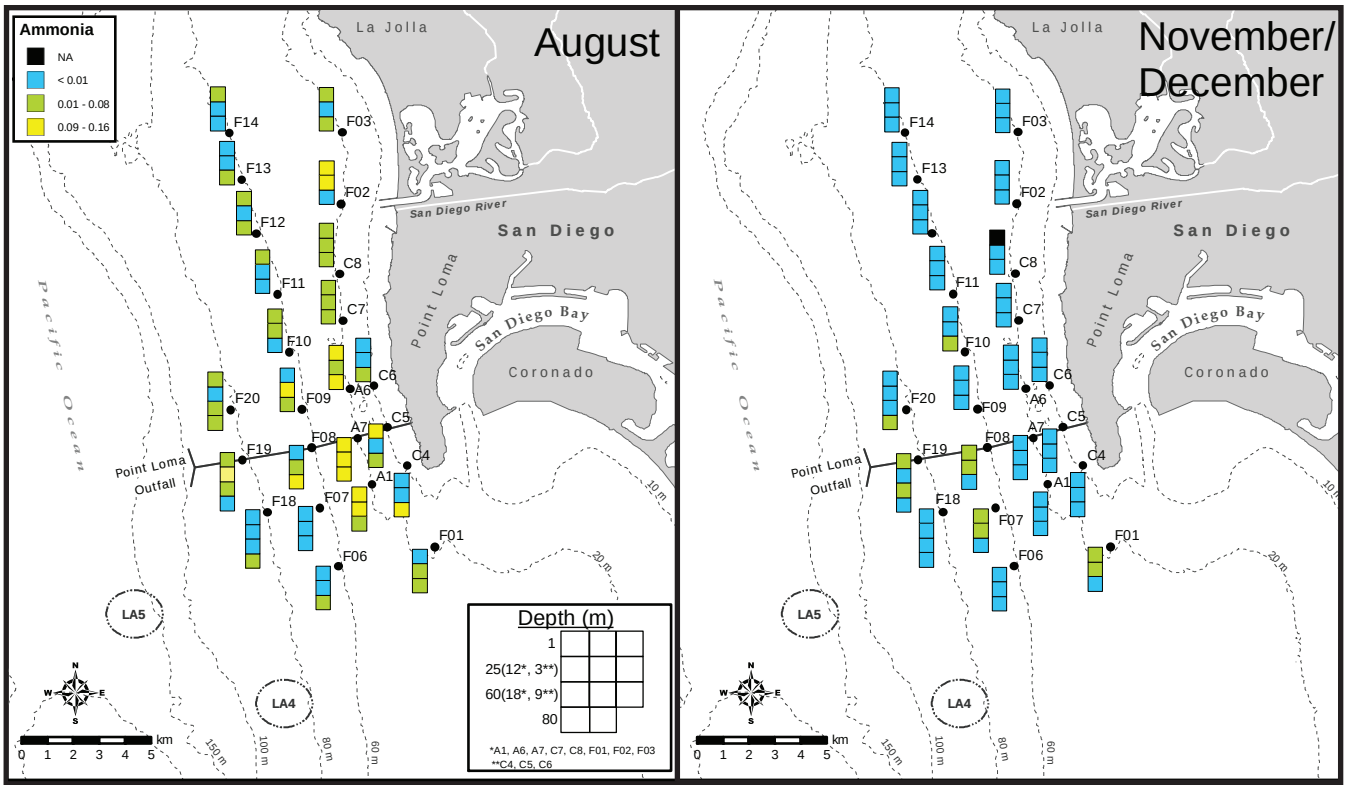

Figure 3.5

Distribution of ammonia (as nitrogen, mg/L) in seawater samples collected during the third and fourth PLOO quarterly surveys in 2010. NA=not analyzed. See text and Table 2.1 for sampling details.

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